ACCELERATION OF THIN PLATES BY EXPLODING FOIL TECHNIQUES

by

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FOREWORD

Acknowledgment is made to other members of the Pulse Power Laboratory for help with this experimental program: Capt Weis, Airmen Griffin, Lawrence, and Webster, and photographic technicians Sgt Henrich and Mr. Johns. This study could not have been completed on time without considerable teamwork and support of various agencies on Kirtland Air Force Base.

A more detailed report will be published at a later date which will include more of the physical phenomena occurring in this experimentation. Also a classified report will be published on the results and their application to weapon phenomenology.

ABSTRACT

A technique for the acceleration of thin plates to high velocities by exploding foils has been developed. These plates, primarily Mylar and Lucite with areal dimensions up to 3 inches x 3 inches and thicknesses from a few mils to a quarter of an inch, are used to produce a high-impulse, short-time loading of materials for the purpose of material dynamics at high pressures. Velocities up to 5×10^5 cm/sec have been achieved. A brief description of equipment including the capacitor system, cameras, backlighting, etc., is given. A detailed description of the construction of the transducers and the characteristics of different types of transducers including such items as efficiency of energy transfer, velocities obtainable, and matching of transducer to the capacitor system is given. Methods of velocity determination are described and photographs of these high velocity plates from high-speed cameras are shown.

PUBLICATION REVIEW

This report has been reviewed and is approved.

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ILLUSTRATIONS

1. INTRODUCTION.

The Air Force has a requirement to determine the response of various materials and structures to intense external loads of short duration. Primarily, failures of material under these types of loadings are those of spallation, internal fracture (cracking, delamination, etc.), chemical changes, and structural deformation. Shock loading of materials by use of high-explosive, plane-wave generators in direct contact with a medium have been used in the past to produce shock waves of high pressures.[1 2] These techniques were developed primarily to aid in the determination of the dynamic equation of state of materials under these high-pressure conditions. More recently, higher pressures have been obtained by impacting plates which were accelerated by high-explosive plane-wave generators.[3 4 5] These higher pressures resulted from the increase in the rate of transfer of momentum into the target material. These techniques in general require rather special facilities and are lengthy in their preparation. Efforts have been made by Lundergan[6] to use techniques better adapted to more conventional laboratory procedures. He has produced high-pressure, short-duration shocks by impacting a plate driven by a high-pressure air gun, with excellent results. However, most of these techniques require considerable time to develop and in general could not accelerate plates thin enough to be of interest in the present program.

The needs of the Air Force were to determine the dynamics of the above-mentioned types of failure as a function of width and shape of the shock wave and the peak pressure in the shock wave. Therefore, laboratory development of a technique to study this problem was started early in 1959. The techniques have varied along a range of pulse parameters which are produced by the impacting of an exploding foil-driven plate; the thickness of the plate determines the pulse duration, the velocity of the plate determines the peak pressure, and the materials and environments somewhat determine the shape of the pulse. For flyer plates and targets of similar materials, theoretically a square wave is generated in the target. The thin plates are accelerated to high velocities by first producing a very high pressure metallic vapor by rapid joule heating of an aluminum foil. This high pressure gas then accelerates the flyer plate to a high velocity. The vaporization of the foil is produced by discharging a moderate energy capacitor system through the foil in a very short time.

In general it requires several shots to get one data point for a particular flyer and target thickness, and because the requirement was rather urgent, the technique of using exploding foil-driven plates was well adapted, since as many as 15 to 20 shots could be performed in an 8-nour day.

When a shock wave produced by the impacting plates reaches an interface such as the back surface of a material, a tension wave reflects back into the material. It interacts with the remainder of the incident compression wave and the resultant stress is the sum of both the compression and tension stresses. This net tension increases with time by this process. When it then becomes greater than some critical value for the particular material, failure occurs. On rear surfaces this causes spallation of high speed particles.

This particular series of experiments dealt with determining the response of the material as a function of peak pressure, pulse width and shape, and other conditions such as vacuum or high temperature environments. A typical curve obtained from these experiments is shown in figure 1.

Since this report is concerned primarily with exploding wire and foil phenomena, the discussion is limited to the details of this technique.

2. EQUIPMENT.

The capacitor storage system consists of four 0.5 microfarad Axel capacitors arranged geometrically in a square and connected electrically in parallel as shown in figure 2. The outside of the capacitor bank is ground, the high-voltage plate being in the interior of the bank; the bank is filled with high-grade transformer oil to allow closer spacing between high voltage parts without electrical breakdown. The metal parts of the bank are made of aluminum.

The experimental area is located on the top of the bank in the center. It is possible to evacuate the air from the explosion area if one desires to do work in a vacuum or some other atmosphere.

The capacitors are charged through a 3-megohm resistor by a commercial power supply. The charging current is normally about 3.5 milliamps. The capacitors can be charged to 125,000 volts with a total energy storage capability of approximately 16,000 joules. The total capacitance is 2 microfarads, and the inductance of the system is approximately 127 millimicrohenrys. This arrangement gives a ringing frequency with a dead short as a load of about 1/3

megacycle. This implies a time-to-peak current of 3/4 microsecond.

The system is fired by triggering a three-electrode pressurized spark gap switch by a thyratron circuit through a pulse transformer to give a 45-KV triggering pulse. The gap is pressurized with water-pumped nitrogen gas from atmospheric to 60 psi to allow the bank to be fired at different voltages with reliable triggering. The spark-gap switch, as shown in figure 3, has two semi-spherical electrodes each with a radius of 1 inch. These electrodes are separated with a fixed spacing from 1/4 inch to 1 inch apart. The electrodes are made of stainless steel with tungsten inserts on the tips. The housing is elipsoid in shape with a maximum outside diameter of 5 2/3 and is made from a single piece of nylon. The triggering electrode is a 1/16-inch-diameter tungsten rod with a 3/16-inch-diameter teflon insulating sleeve. It is placed in the center of the lower main electrode, which is at some high negative potential, with the tip even with the surface of the main electrode. At voltages below 50 KV the switch fires reliably for several hundred shots; however, at repeated firings of 90 to 100 KV the switch needs to be cleaned about every 10 shots. The switch fires within a fraction of a microsecond and has a jitter of about 1/4 of a micro-second.

3. DISCUSSION.

The critical portion of this pressure impulse technique is the transducer that is used. Several types of transducers have been developed which will accelerate thin plates to high velocities. For accelerating thin plates, on the order of 3 mils to 10 mils of Mylar, a load known as a type G transducer is used; this is shown in figure 4 and is made up as follows:

A block of Lucite 3 inches square with a 4-mil-deep by 2-inch-wide groove through the middle is used as a backup block. Five-mil-thick copper electrodes are then glued to the block with Eastman 910 adhesive. Then an aluminum foil is placed across the electrodes. A thin coat of conducting silver is used between the foil and the electrodes. The foil is in no other way bonded to the Lucite, since other bonding causes nonuniform foil vaporization. Over this entire block is placed a sheet of Mylar which is glued to the assembly. In this way the foil is completely encapsulated, such that a high temperature is created in this restricted volume, thus increasing the pressures behind the flyer. Then a top piece of Lucite with a hole in the center corresponding to the desired

dimensions of the flyer is glued to the Mylar. This top piece has both gas ports and viewing slots. The object of the ports is to help direct the gas flow in such a direction as not to obscure the viewing of the plate during flight. The viewing slots are used to see the Mylar plate with the camera very soon after it breaks out of the load. If the slots are not present, the luminous vapor causes the whole side of the Lucite block to light up, and the plate cannot be seen until after it clears the top of the Lucite load.

For firing, the completed load is placed between the electrodes of the bank, and the copper electrodes of the load are firmly clamped to the bank electrodes. When the bank discharges and the foil vaporizes, the high-pressure aluminum vapor tears out a piece of Mylar the exact size of the hole in the upper block and accelerates it to a high velocity.

For accelerating 15-mil to 125-mil-thick flyers of Lucite, polyethylene, and aluminum, etc., a different type of load is used—a type H transducer, shown in figure 4. A similar block, electrodes, and foil are used as before; then a solid block of approximately 1/8-inch-thick Lucite is glued over the assembly. The 1-1/2-inch by 1-1/2-inch Lucite flyer is then placed on the top of the load. A very thin film of mineral oil is used between the flyer and the load for better shock impedance matching. When the capacitor bank is discharged through the load, the foil vaporizes and sends a shock wave through the Lucite block and into the flyer. Enough momentum is trapped in the flyer to cause it to accelerate to a velocity which is much higher than the velocity of the total assembly, which breaks up at late times.

The transducers just described are the two general types normally used; however, certain parameters in the fabrication of these loads must be varied to obtain a large span in the possible velocities for each type of flyer. To achieve high velocities with either type of transducer it is important that the capacitor bank be discharged as efficiently as possible into the foil. The efficiency of discharge for our purposes is dependent on the voltage on the bank, the discharge time, and the thickness of the foil in the transducer.

It has been experimentally determined that there is a particular thickness foil which gives the best efficiency at particular voltages for each type of load. In general, the higher the voltage, the thicker the foil must be to obtain good efficiencies. The foils used vary between 0.17 mil to 1 mil in thickness. The

effect of foil thickness on flyer velocity can be seen in figure 5. The curves will fall off on the high end because a limiting vapor phase pressure is reached for a certain mass of foil. The discharge time is important since it is desired to obtain an essentially instantaneous high pressure vapor behind the Mylar before it has time to break out and leave the transducer. With the Lucite flyers, a very steep-fronted narrow-width shock is desired in order to trap as much momentum as possible in the flyer.

For our capacitor bank a single discharge pulse is approximately 1.5 microseconds in duration. Thus one does not experience a "dark pause" as one would with a slower and lower voltage system. At most we see a slight discontinuity in the current trace. To complete the velocity span of interest, one is interested in obtaining lower velocities with the same type of flyers. This cannot be done entirely by merely firing the system at a lower voltage—and hence a lower energy—since the foils do not vaporize as uniformly and the Mylar does not "break out" as cleanly at very low voltages. Hence, lower velocities are not in general obtained by lowering the efficiency of energy discharged into the foil, but rather by lowering of the efficiency of energy transfer between the high pressure vapor and the flyer. With Mylar loads this is achieved by decreasing the thickness of the backup block, even to the point of using another sheet of Mylar as a backup block. Thus when the load is fired, a high pressure is developed and both sides of the load "break out," relieving the high pressure almost immediately, and a low flyer velocity is obtained with a clean "break out."

For the Lucite-type transducers a slightly different technique is used to lower the energy transfer efficiency. In this type of load one merely increases the thickness of the top piece of Lucite on the load. Normally blocks of between 1/8- and 1/2-inch thicknesses are used. This thickness increases the distance the shock has to travel before reaching the flyer and thus degrades the shock such that a smaller amount of momentum is transferred to the flyer. The effect of this on flyer velocity can be noted in figure 6. Graphs of flyer velocity versus bank voltage for different flyer thicknesses and different flyer dimensions can be seen in figures 7, 8, and 9.

Thus by varying the voltage on the bank and by changing parameters in the transducer as exhibited by the graphs, one is able to achieve any velocity within a reasonable velocity spread.

Typical flyers, their dimensions and masses, and approximate velocity range and efficiencies, can be noted in the table in figure 10.

Several different types of transducers have been designed for particular applications, some of which are shown in figure 11. Flyers of metal and plastics up to three inches square have been successfully accelerated.

A continuing effort is being made to fabricate differently designed transducers to obtain higher flyer velocities and more uniform impact planarity. It is believed that velocities up to twice those which are now being obtained should be fairly easy to obtain. New ideas are constantly being tried.

4. DIAGNOSTICS.

Both electrical and optical diagnostic equipment is used on each experiment. A 100-KV electrostatic voltmeter is used to measure the initial voltage to which the capacitors are charged, and therefore the total stored energy can be calculated. All other electrical diagnostic signals are run through styroflex cables to oscilloscopes located in an electrically and magnetically shielded room. Such parameters as di/dt, current, voltage, delays, timing signals, and light output can be monitored. Because of the fast rise times, high currents, and high voltages involved, the accuracy of current and voltage measurements is poor. However, the waveform of the di/dt trace gives a good indication of whether the load was matched to the conditions on the bank and whether an efficient discharge was obtained. For a high efficiency discharge, the di/dt trace shows a single complete cycle, corresponding to single current pulse. For a slightly lower efficiency discharge, one notes several cycles on the di/dt trace. For a poor efficiency discharge, one notes a long time oscillatory trace. Since the flyer plate starts moving in a few microseconds, any energy into the foil vapor at later times does not contribute to the acceleration of the plate.

A Beckman and Whitley Model 189 framing camera is used to photograph the flying plate during flight. This high-speed framing camera is capable of taking 25 frames at framing rates as high as 4 million frames per second. Normally a framing rate between 50,000 and 2,000,000 frames per second is used. For the Mylar-type transducers, the luminous vapor produces enough light to illuminate the flying plate for proper film exposure. For the Lucite-type transducers, an external backlight unit must be used to illuminate the flying Lucite plate. The backlight used is a xenon flash lamp with a cylindrical lens of

plexiglass rod, triggered by the firing circuit. This gives a backlight of approximately 150 microseconds duration.

A Beckman and Whitley Dynafax camera is used to photograph the target after impact. This camera is capable of taking 224 frames at framing rates up to 26,000 frames per second. A Beckman and Whitley strobe unit is used to provide backlighting for this camera.

For safety reasons the bank is operated from a control room adjacent to the system. All controls, both those for the capacitor band and those for the cameras, are controlled from this control room.

If this technique of flying plates is to be of maximum usefulness, one must be able to accurately determine the impulse imparted by the flying plate to a target material. This can be accomplished if the mass, area, and velocity of the flyer before impact are known.

For Mylar, the mass is determined by measuring the dimensions of the flyer and by calculating its mass, knowing its density. For the Lucite, the flyers are accurately measured and weighed.

The velocity of the flyers is determined from high-speed photographs of the flyer on each shot. Examples of these are shown in figures 12 and 13.

Making an accurate determination of the velocity on each shot is very important in most experiments, since that parameter is normally the one that has the most effect on the final result of the experiment. Al'tschuler's[4] technique for the determination of the equation of state by measuring the flyer plate velocity and the free surface velocity only, requires an accurate measure of the flyer velocity.

Ordinarily 20 frames of film are obtained during the time of flight of the flyer on the high-speed camera. The 35 mm negative film is read on a Richardson film reader to determine the difference in movement of the flyer between frames. These differences are obtained by measuring the distance between the frame edge and the object on each frame and subtracting the measurements between consecutive frames. However, because of the rotating mirror in the high-speed camera, the field of view and the total frame size change with each frame on the camera.[7] Thus, to obtain the correct movement between frames of the flyer, correction factors must be added to the

measurements that are obtained directly from the film to account for this field shift and change in frame size. The measurements from the film are fed into a computer along with magnification factors, frame edge corrections, and the framing rate. The corrected points are fitted to a straight line by a least squares fit by the computer. A straight line fit is used, since from many tests it is known that the flyer undergoes an unmeasurable acceleration or deceleration during the time the flyer is being photographed just before impact. Obvious errors in the film reading can easily be detected from the data and are rejected. The remaining data are rerun to obtain a corrected velocity. Three independent velocity determinations are made at different positions over the flyer length. The final corrected and averaged velocity is fed into the computer, and momentum, kinetic energy, errors, and other parameters of interest are printed out as shown in figure 14.[8]

A similar technique is used to obtain the velocity of the target after impact. The film from the Dynafax camera is read for target displacement between frames and a velocity is computed using known magnification factors and the camera framing rate. The photographs taken on the Dynafax are also useful in determining that the damage is due to the flyer alone and is not caused by some other effect such as the target hitting an obstruction or the rest of the transducer hitting at a later time. In the opinion of the authors, determination of the velocity of the flyer during each shot is an absolute necessity. The photographic techniques developed for this purpose are ideally suited to this requirement, primarily because these techniques constitute a passive measurement which does not interfere with the experiment.

It also gives one information on other parameters of the experiment such as the physical condition of the flyer before impact and how plane the flyer impacts.

Other techniques, such as pins, were also used in conjunction with photographing to check the velocity measurement. The measurements agree quite well if one corrects the pin measurements for any tilting of the flyer caused by the pins. A velocity measurement is needed on each shot also since there are many parameters besides stored energy on the capacitors which cause a change in the velocity. In other words, for a given voltage on the bank, the velocity of the flyer is not constant. A poor efficiency discharge into the foil, or an arc-over from the electrodes to a metallic sample will result in a much lower

velocity than would be expected. In vacuum one does not get as high a velocity because at some time during the vaporization process the foil vapor resistance is higher than an air path between electrodes, and therefore some portion of the energy is dissipated in an arc rather than usefully in heating the foil. Or, tighter electrical connection may result in increased current into the load and a higher velocity will result. The scatter of velocities for a particular set of conditions exceeds the experimental limits of our velocity determinations. Therefore, these velocity changes can only be taken into account if a velocity measurement is made on each shot.

As previously mentioned, photographs of the flyer enable one to measure the planarity of impact and to determine the condition of the flyer before impact. If Lucite flyers are used in the same type or in similar type of load configurations as Mylar, one finds that in general the Lucite breaks up into many pieces before impact or tilts very badly. Thus by taking photographs one is able to discount those shots and thereby increase the reliability and accuracy of the total experiment.

The only disadvantage to these photographic techniques is that one must allow the plate to travel through some distance such that an accurate velocity measurement can be made. In this experiment these distances are from 1/4 to 3/4 inch. This much travel through atmospheric air can cause a precursor air shock which produces a small shock in the material which is usually overridden by the much stronger shock wave from the flyer impact. This occurs even for negligible flyer travel in atmospheric air; however, these much weaker air shocks can be corrected for in machine codes of the shock hydrodynamics; and can be eliminated completely by using a hard vacuum as the environment. Figure 15 shows a series of photographs of a type G Mylar assembly exploded toward the camera to exhibit the uniform vaporization of the aluminum foil. Figures 16 and 17 exhibit the various types of damage caused by these high-pressure, short-duration shock waves. Figure 15 shows the entirely different types of damage that occur between long and very short impulsive loadings. A piece of 1/4-inch-thick lead plate was impacted with a type H load using a 1/8-inch-thick Lucite flyer. The flyer produced a loading time of approximately 2 microseconds. The effect of this impulse was primarily structural deformation. On another 1/4-inch-thick lead sample an 8-mil Mylar flyer in a type G load was impacted. The effect now was spallation caused by the higher peak pressure

in the shock wave. This flyer produced a loading time of about 0.2 microsecond. Both impacts were at approximately the same impulse, causing two entirely different types of failure. In figure 16 other types of damage on a wide variety of materials are illustrated.

This technique has many applications, and in slightly different form is being used with good results at other laboratories such as Boeing Aircraft Company and in recently started work at the Naval Research Laboratories.

With slight modifications, many types of experiments involving shock hydrodynamics can be conducted. For instance, foils exploded directly on the surface of materials can also produce high intensity shock waves. But not enough is known of the incident pulse produced in the material primarily because of poor electrical measurements of high-voltage, fast-discharging systems. However, those techniques are quite useful in equation of state measurements as plane wave generators where the shock velocity and the particle velocity are measured by means of a free surface measurement determination.

The authors feel that this and similar techniques of producing plane waves of short duration will come into even greater use in the future in other experimental laboratories. The plate slapping technique has provided technical personnel of the United States Air Force with an improved understanding of material dynamics in the realm of very short impulsive loadings and is aiding in the development of new materials which will withstand high-pressure, short-duration shock waves.

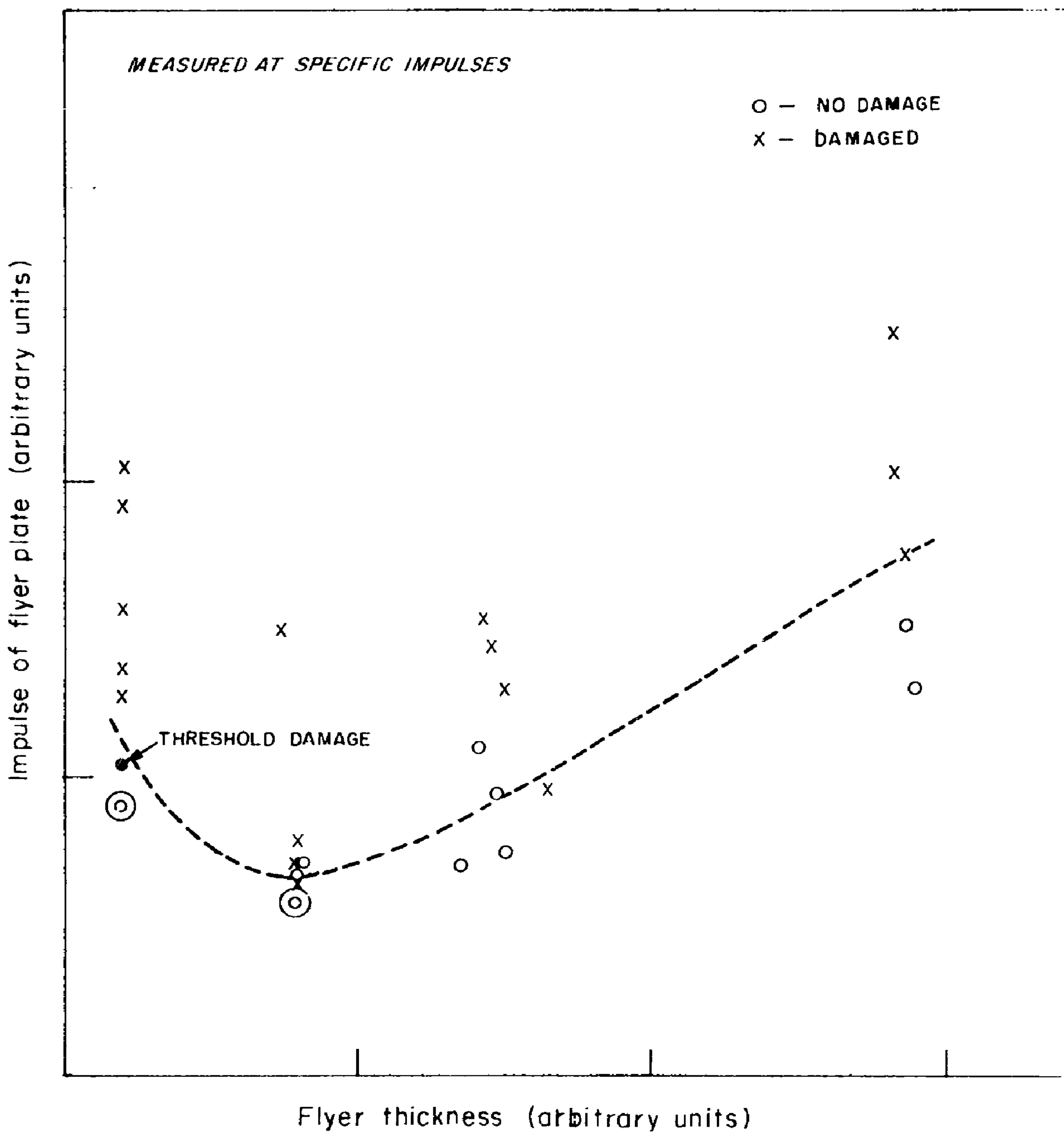

Figure 1. Variation of damage thresholds as a function of plate thickness. An actual graph of an experimental determination of the impulse required to produce damage at different pulse widths

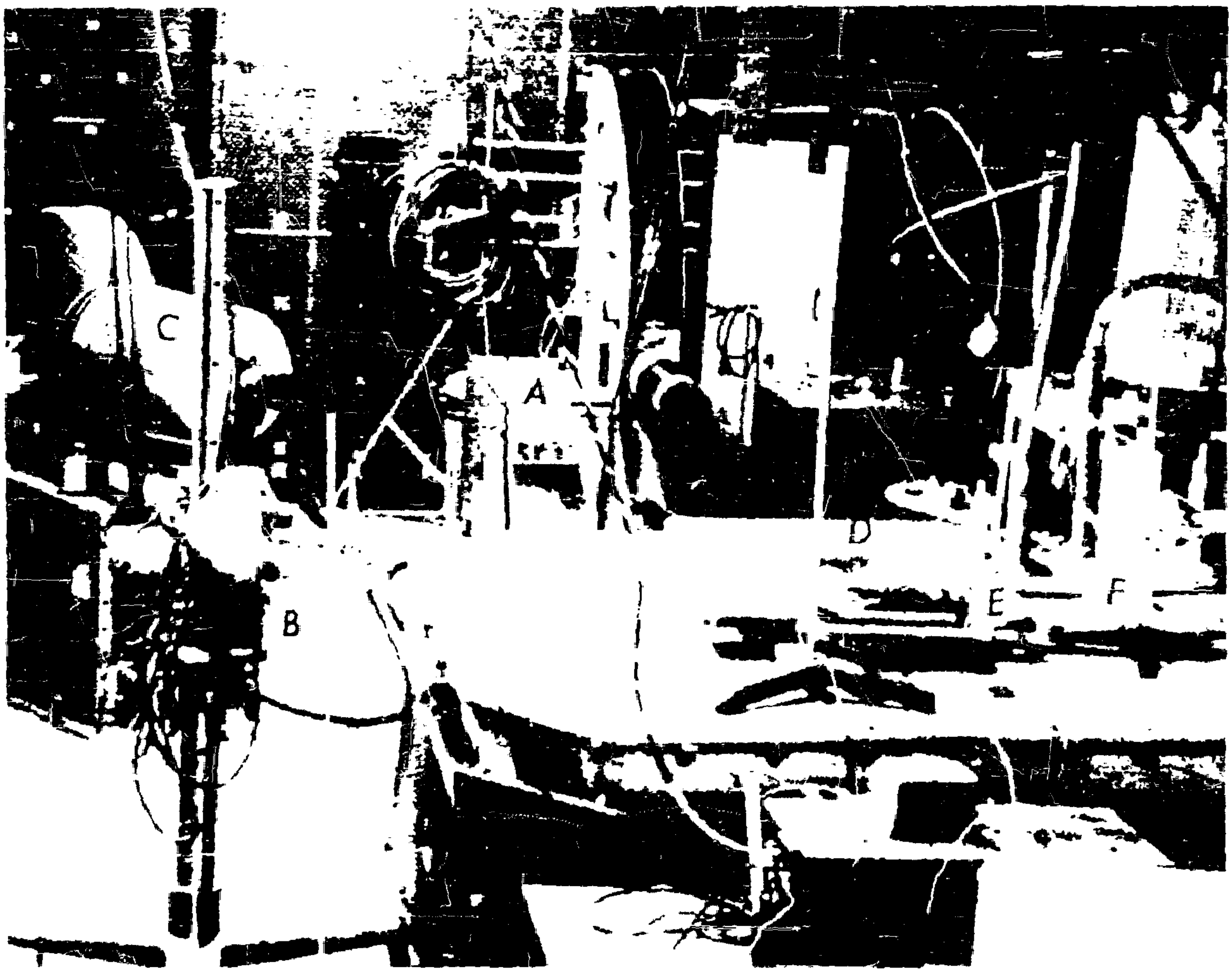

Figure 2. View of laboratory and high speed cameras. General overall view of experimental room in the Pulse Power Laboratory. A. Model 189 framing camera used to photograph flying plates. B. Dynafax camera used to photograph target assembly after impact. C. Model 439 streak camera used to photograph expansion rates. D. Load assembly and experimental area. E. Backlight for Model 189 camera. F. Fresnel lens and backlight for Dynafax camera.

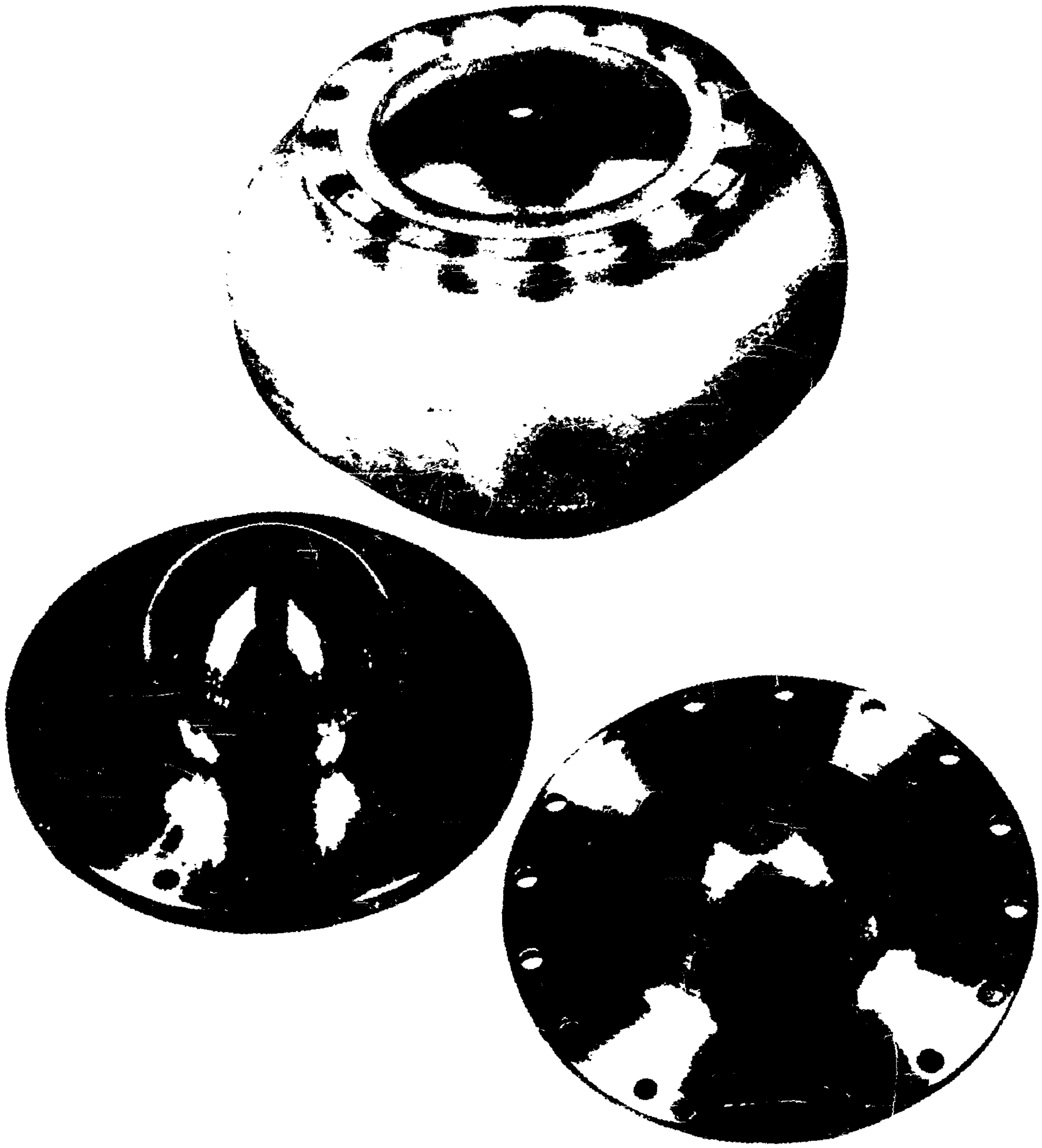

Figure 3. Three electrode triggered spark gap. Illustrated here are the main elements of the switch used on the 16,000 joule capacitor system. The triggering electrode is concentrically mounted in the lower electrode which is charged to a high negative potential.

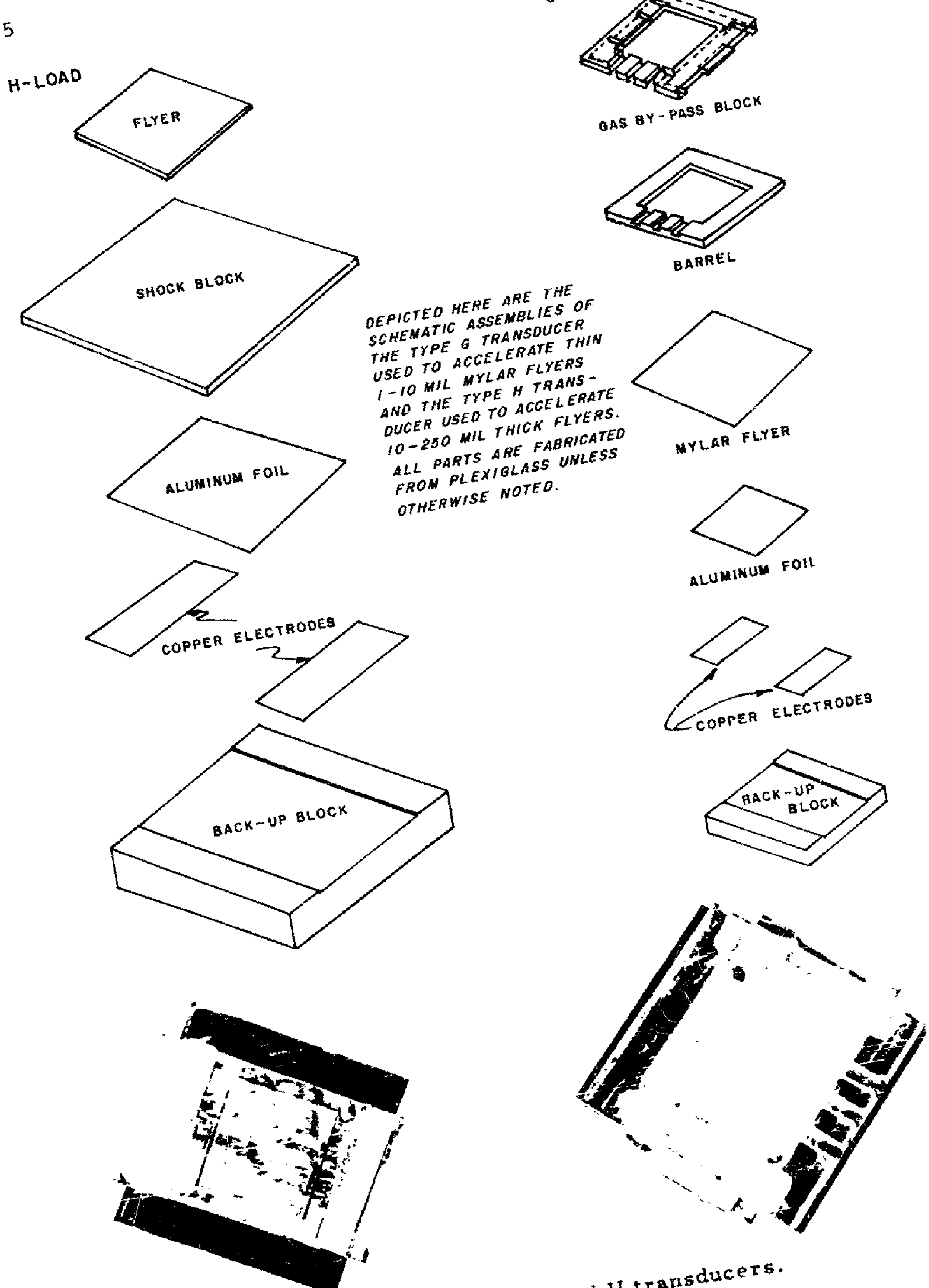

Figure 4. Type G and H transducers.

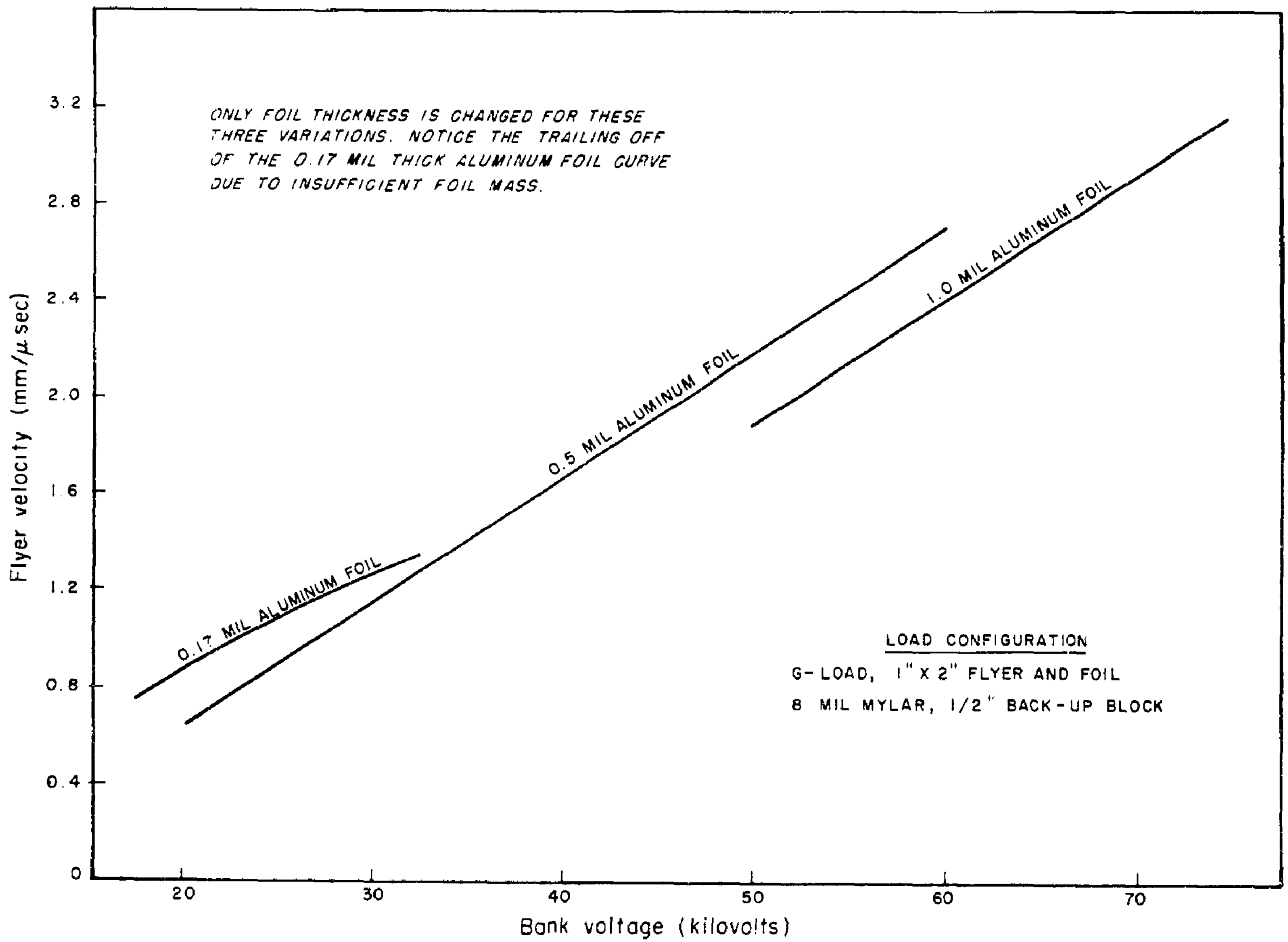

Figure 5. Flyer velocity as a function of initial voltage showing effect of variation of foil thickness.

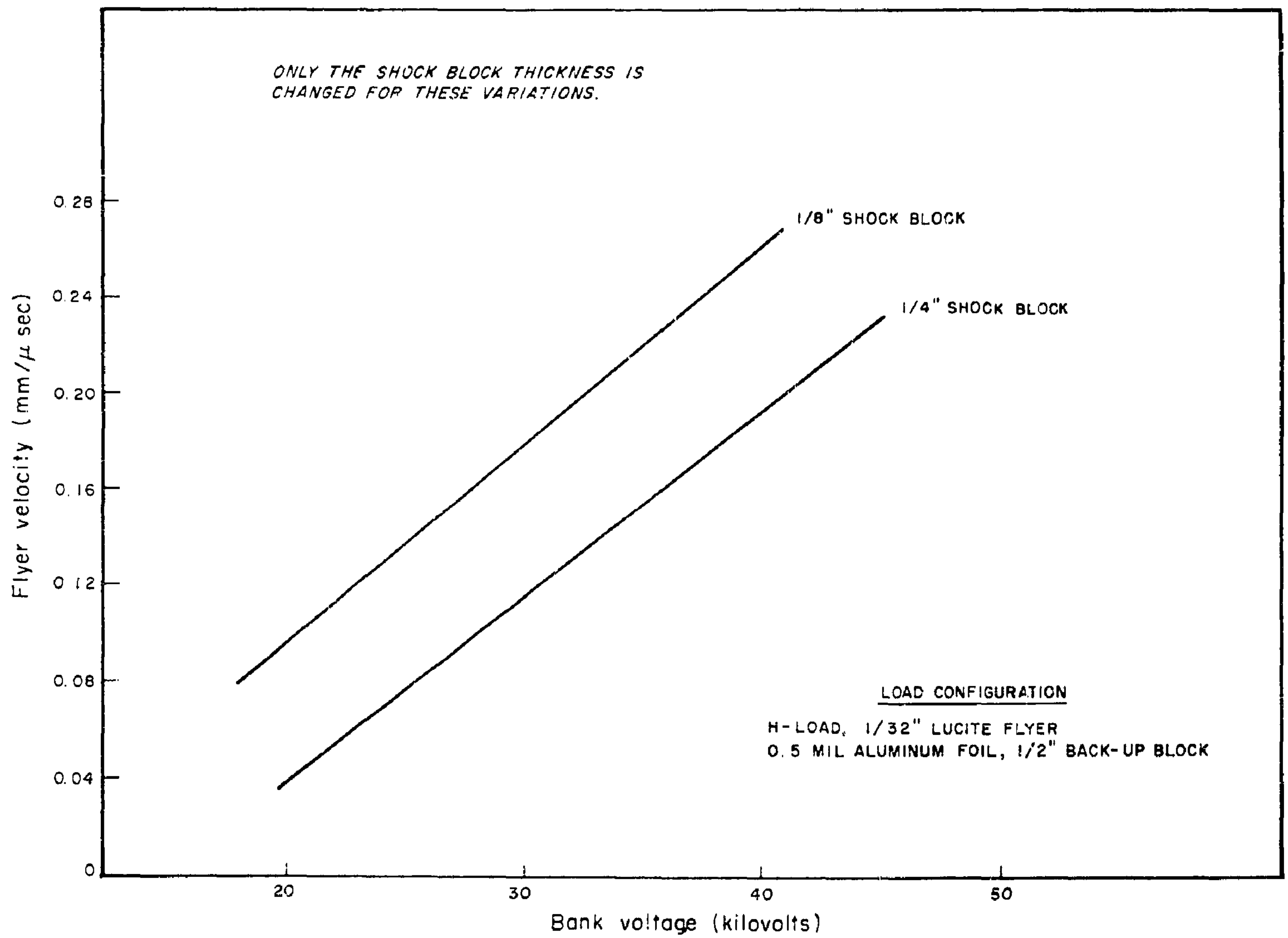

Figure 6. Flyer velocity as a function of initial voltage showing effect of variation of shock block thickness.

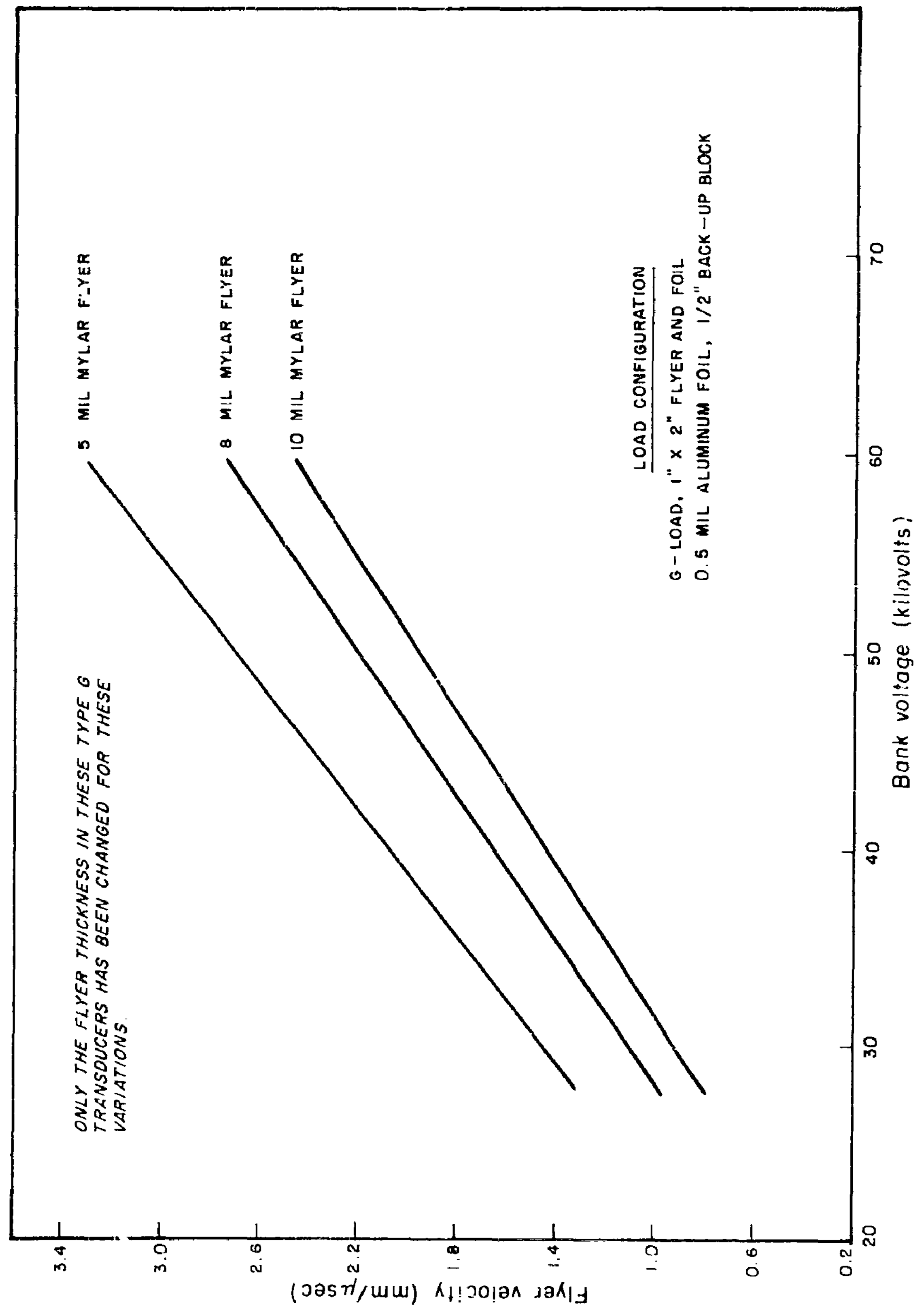

Figure 7. Flyer velocity as a function of initial voltage showing effect of variation of flyer thickness. (Type G load)

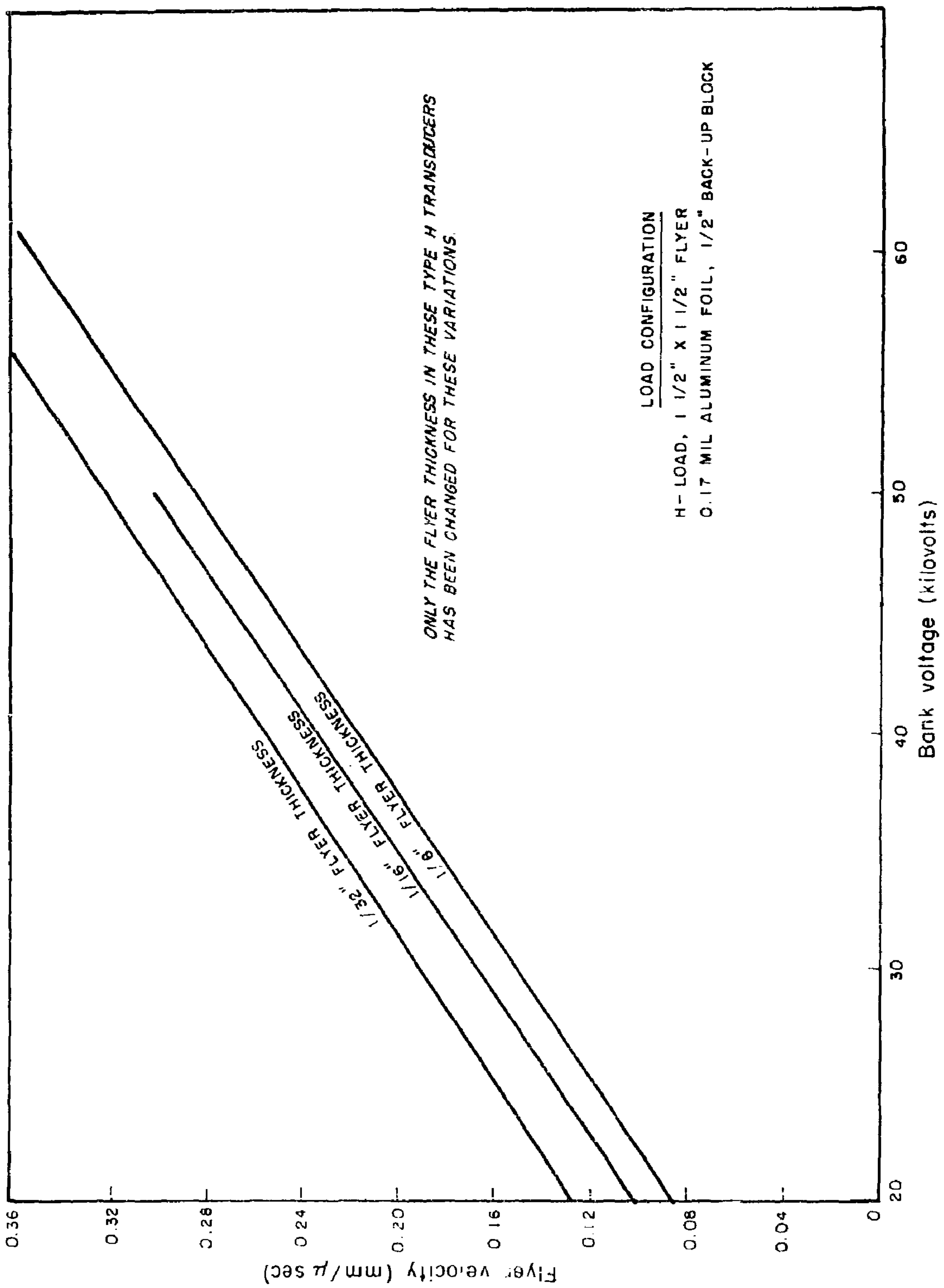

Figure 8. Flyer velocity as a function of initial voltage showing effect of variation of flyer thickness. (Type H load)

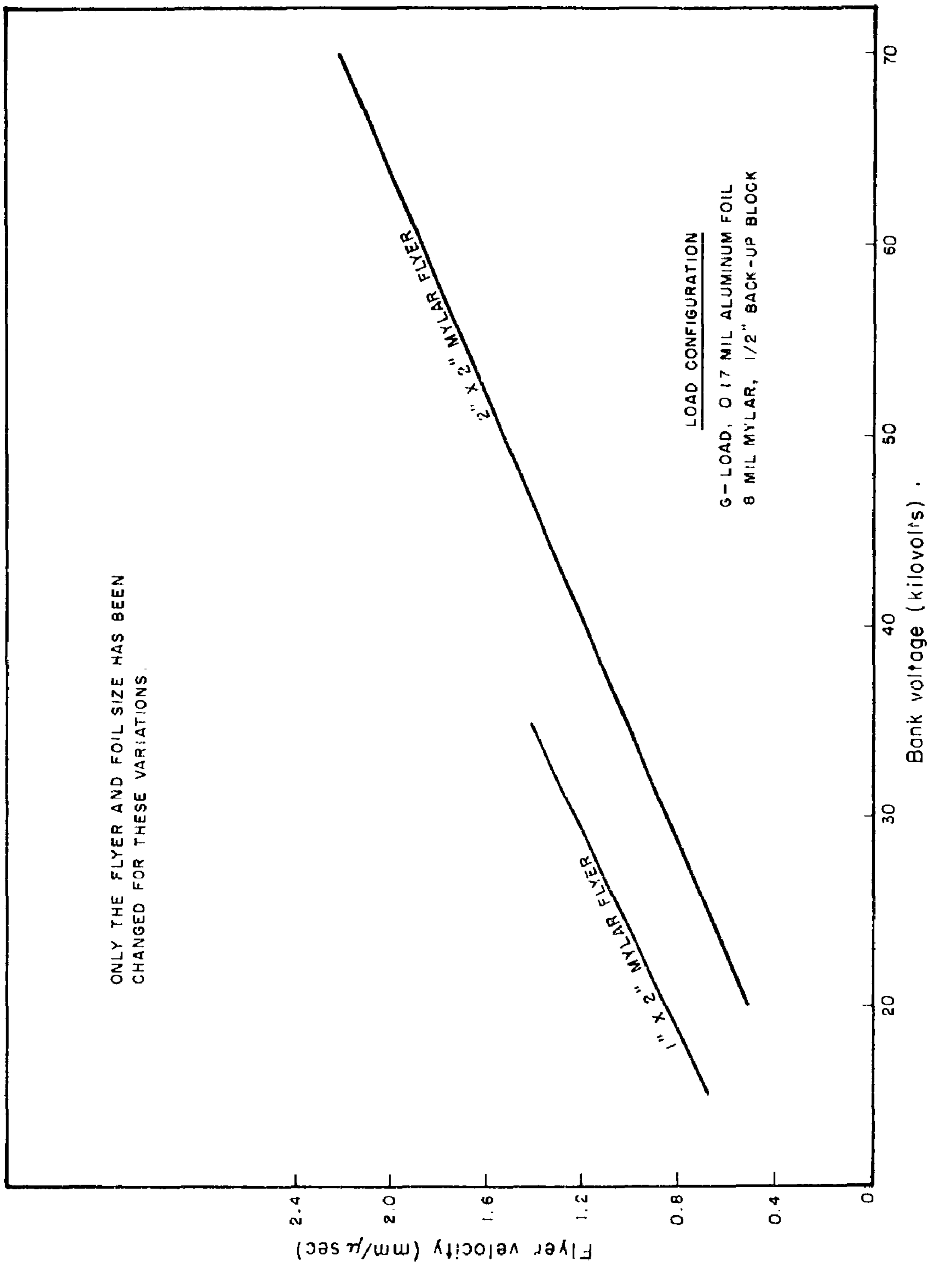

Figure 9. Flyer velocity as a function of initial voltage showing effect of flyer size.

FLYER MATERIAL	TRANS-DUCER TYPE	FLYER DIMENSIONS	FLYER THICKNESS (APPROX.)	FLYER MASS (APPROX.)	VELOCITY RANGE OBTAINED	EFFICIENCY RANGE OBTAINED
Mylar	G	1" X 2"	5 mil	.23 grams	.2 - 3.0 mm/μ sec	20-50 %
Mylar	G	1" x 2"	8 mil	.37 grams	.2-5.0 mm/μ sec	20-50 %
Mylar	G	1" X 2"	10 mil	.45 grams	.2 - 4.5 mm/μ sec	20-50 %
Mylar	G	2" X 2"	5 mil	.45 grams	.2 - 2.5 mm/μ sec	20-40 %
Mylar	G	2" X 2"	8 mil	.75 grams	.2 - 3.0 mm/μ sec	20-40 %
Mylar	G	2" X 2"	10 mil	.90 grams	.2 - 3.5 mm/μ sec	20-40 %
Lucite	H	1-7/8" X 7/8"	1/32"	1 grams	.04 - 1 mm/μ sec	.5 - 10 %
Lucite	H	1-7/8" X 7/8"	1/16"	2 grams	.04 - 1 mm/μ sec	.5 - 10 %
Lucite	H	1-7/8" X 7/8"	1/8"	4 grams	.04 - 1 mm/μ sec	.5 - 10 %
Lucite	H	1-1/2" X 1-1/2"	1/32"	1.4 grams	.03 - .8 mm/μ sec	.1 - 5 %
Lucite	H	1-1/2" X 1-1/2"	1/16"	2.8 grams	.03 - .6 mm/μ sec	.1 - 5 %

Figure 10. Velocity and efficiency for various type G and H transducers. These are typical values for type G and H flying plate transducers. It is possible to obtain both lower and higher values for the velocities. However at lower voltages flyers do not tear out uniformly and at much higher voltages plate impacts tend to be undesirable as to planarity. The density of Mylar is approximately 1.39 g/cc and of Lucite approximately 1.18 g/cc.

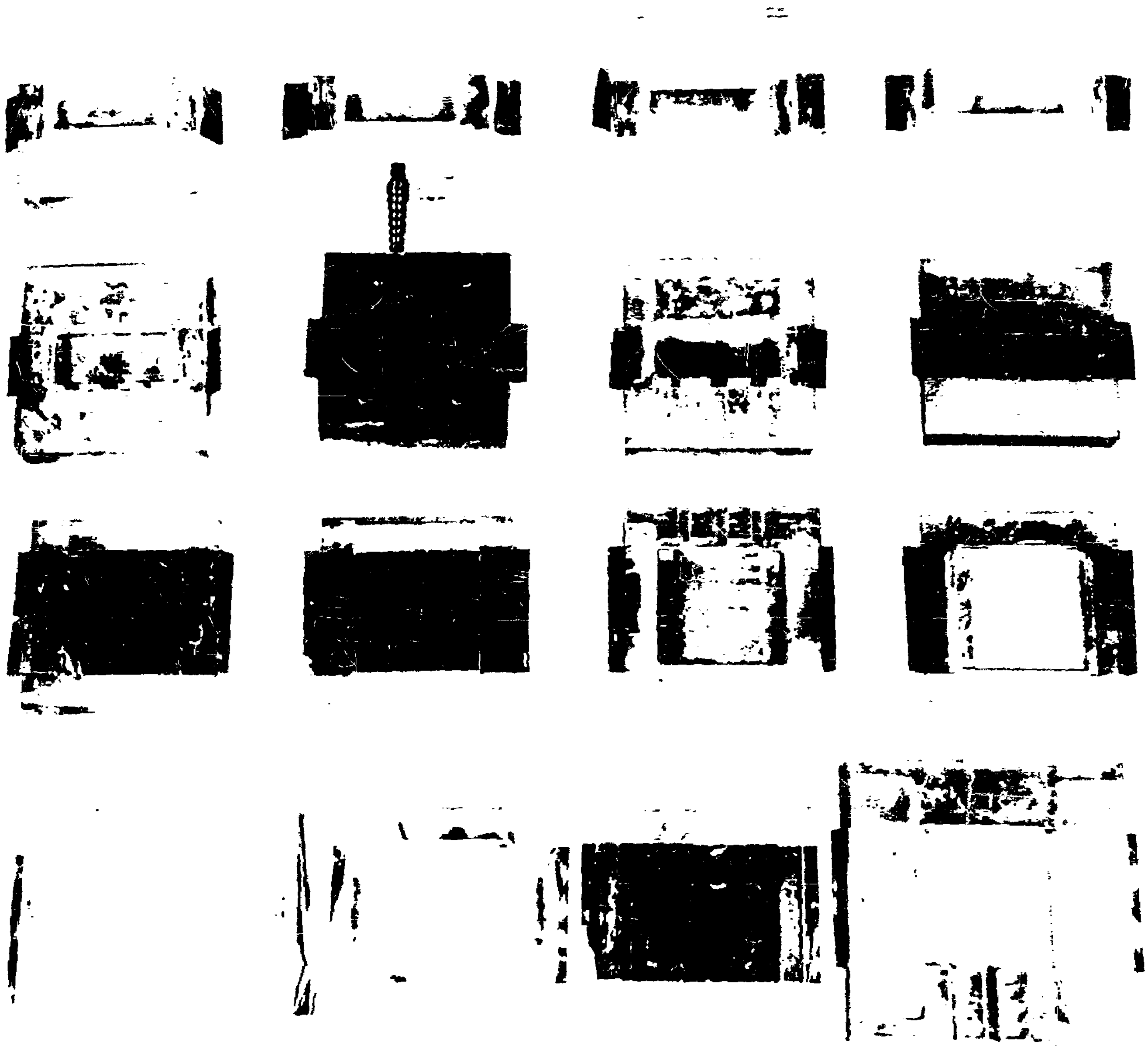

Figure 11. Various transducers. Exhibited here are transducers for various applications. From left to right and top to bottom: Type A 1"x2" Mylar; Type B 1"x2" Mylar for evacuating area between flyer and target; Type C 1"x2" Mylar with slanted gas ports on long side; Type D 1"x2" Mylar with gas ports on all sides; Type E 1"x2" Mylar with viewing slots; Type F 1"x2" Mylar flyer with separated 1/16 inch aluminum transfer block; Type G 1"x2" Mylar with gas baffles on short sides and viewing slots; Type H 1"x2" thick Lucite flyer with shock block; Type I 2"x2" Lucite break out block; Type J 2"x2" milled Lucite break out flyer; Type K 2"x2" Lucite flyer on top of 2"x2" Mylar flyer; Type A 2"x2" Mylar flyer with Mylar backup block; Type G 3"x3" Mylar flyer; Type G 2"x2" Mylar flyer; Type H 2"x2" Lucite flyer; Type G 2"x2" Mylar flyer in a 4"x4" assembly.

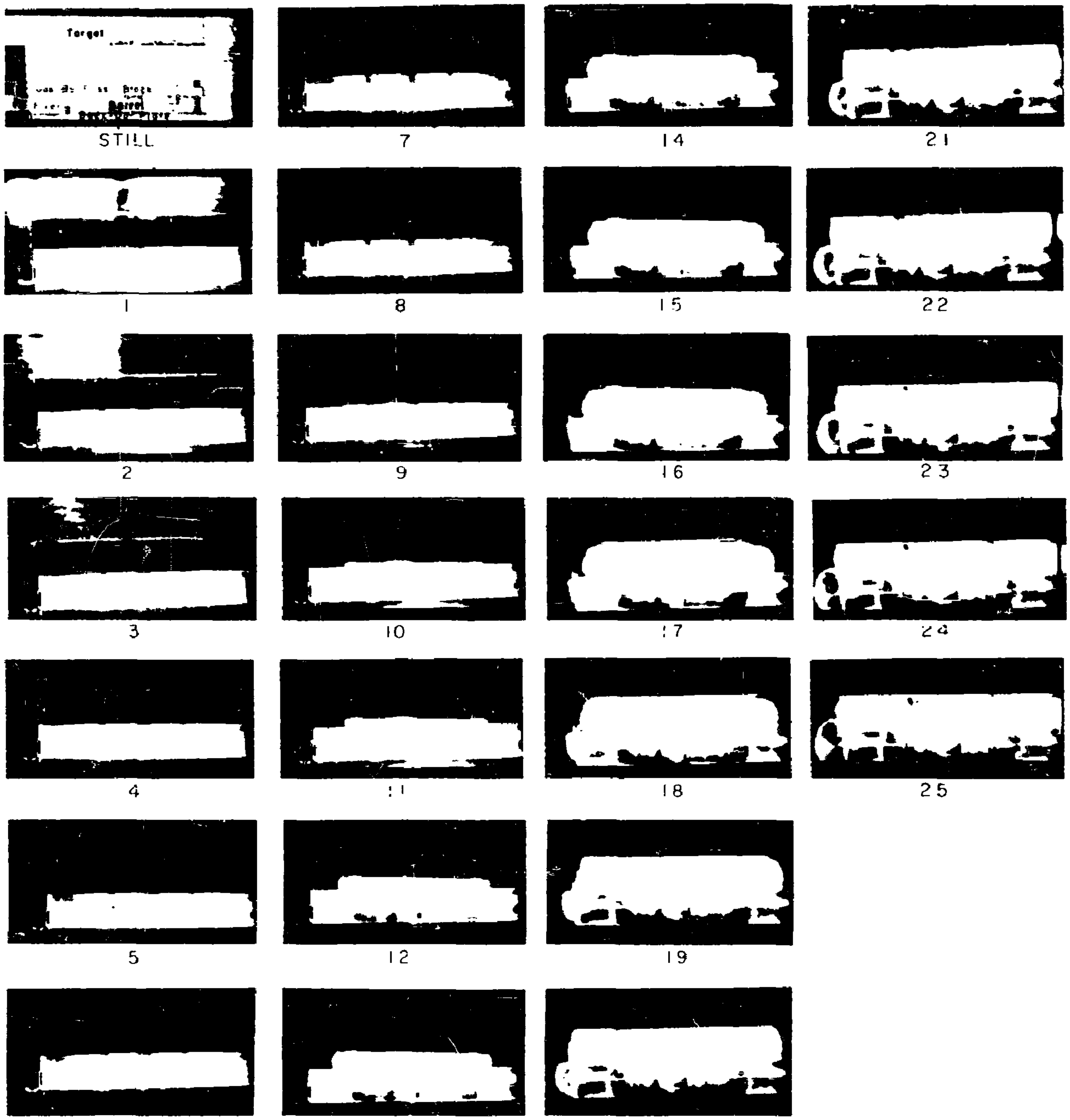

Figure 12. Framing camera photographs of type G Mylar flyers. These pictures taken on a Model 189 framing camera are of the type used to determine the velocity of thin Mylar flyers. In these photographs no backlight is used as the luminous interface between the Mylar and hot accelerating gases is sufficient to give proper film exposure.

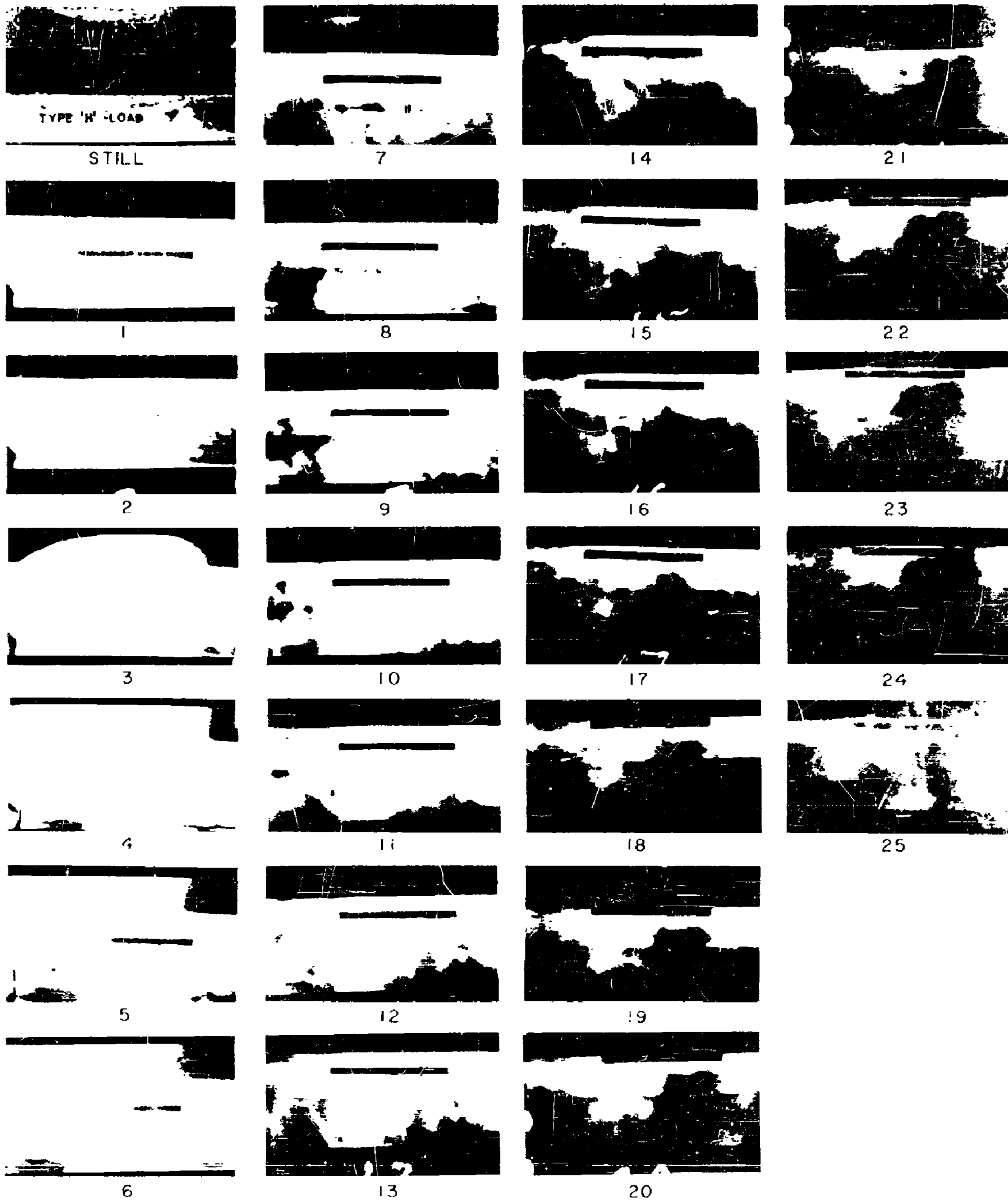

Figure 13. Framing camera photographs of type H Lucite flyers. These pictures taken on a Model 189 framing camera are of the type used to determine the velocity of thin Lucite flyers. In these photographs, use is made of a Xenon flash tube and plexiglass cylindrical lens as a backlight to outline the flyer in flight. One should note that the flyer hits and then rebounds from the target.

PULSE POWER LABORATORY
OUTPUT DATA

MATERIAL CODE	4 - 6
SHOT NUMBER	BMD 37
LOAD CODE	G - 5
FLYER THICKNESS	0.0203 CENTIMETER
FLYER AREA	13.13 SQ. CM
FLYER MASS	0.3705 GRAMS
FLYER VELOCITY	1.38603 MM/MICROSEC
FLYER VEL UNCERT.	0.12765 MM/MICROSEC
FLYER MOMENTUM	51350.83789 DYNE-SEC
FLYER IMPULSE	3910.95 DYNE-SEC/SQ CM
FLYER KIN EN.	355.87 JOULES
VOLTAGE	35.0 KILOVOLTS
DAMAGE CODE	D
TARGET THICKNESS	0.7610 CENTIMETER
TARGET AREA	104.04 SQ. CM
TARGET MASS	122.1991 GRAMS
TARGET VELOCITY	0.00823 MM/MICROSEC
TARGET VEL UNCERT.	0.00085 MM/MICROSEC
TARGET MOMENTUM	100546.44043 DYNE-SEC
TARGET KIN EN.	4.14 JOULES
BANK ENERGY	1225.0 JOULES
MOMENTUM RATIO	0.511
EFFICIENCY	29.05 PERCENT
REMARKS	

Figure 14. Final computer print out. The final data sheet printed out by the computer showing momentum, kinetic energy, errors, and other parameters of interest.

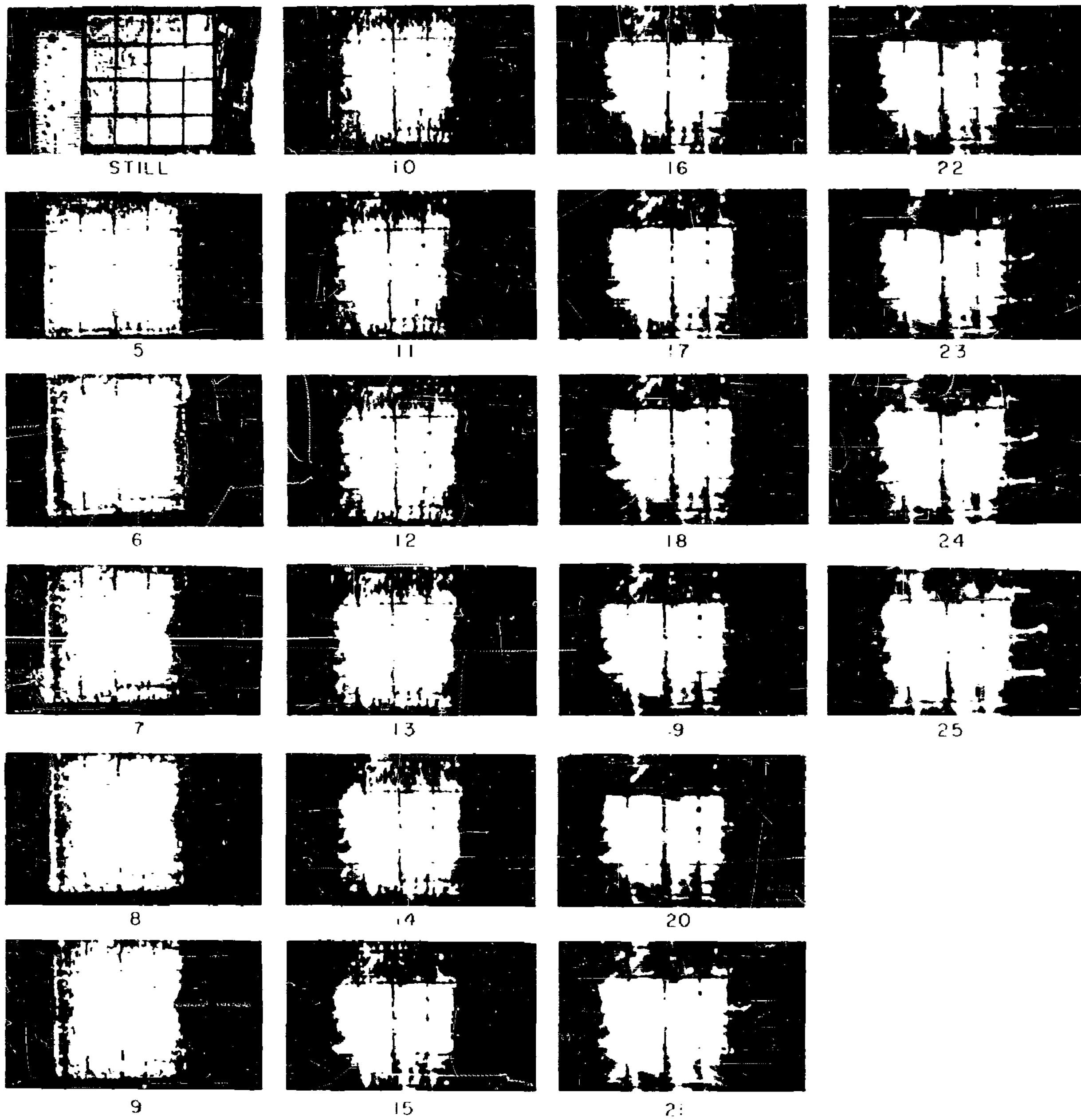

Figure 15. Face-on foil explosion. In this series of photographs a type G Mylar assembly is exploded toward the camera to exhibit the uniform vaporization of the aluminum foil. One should note that the grid on the flyer stays in the same relative position and shape indicating a high degree of planarity. At later times gas can be seen expanding out the viewing slots and gas ports. The flyer has traveled approximately 3/4 inch during this photographic sequence at a speed of approximately 2.5 mm per microsecond.

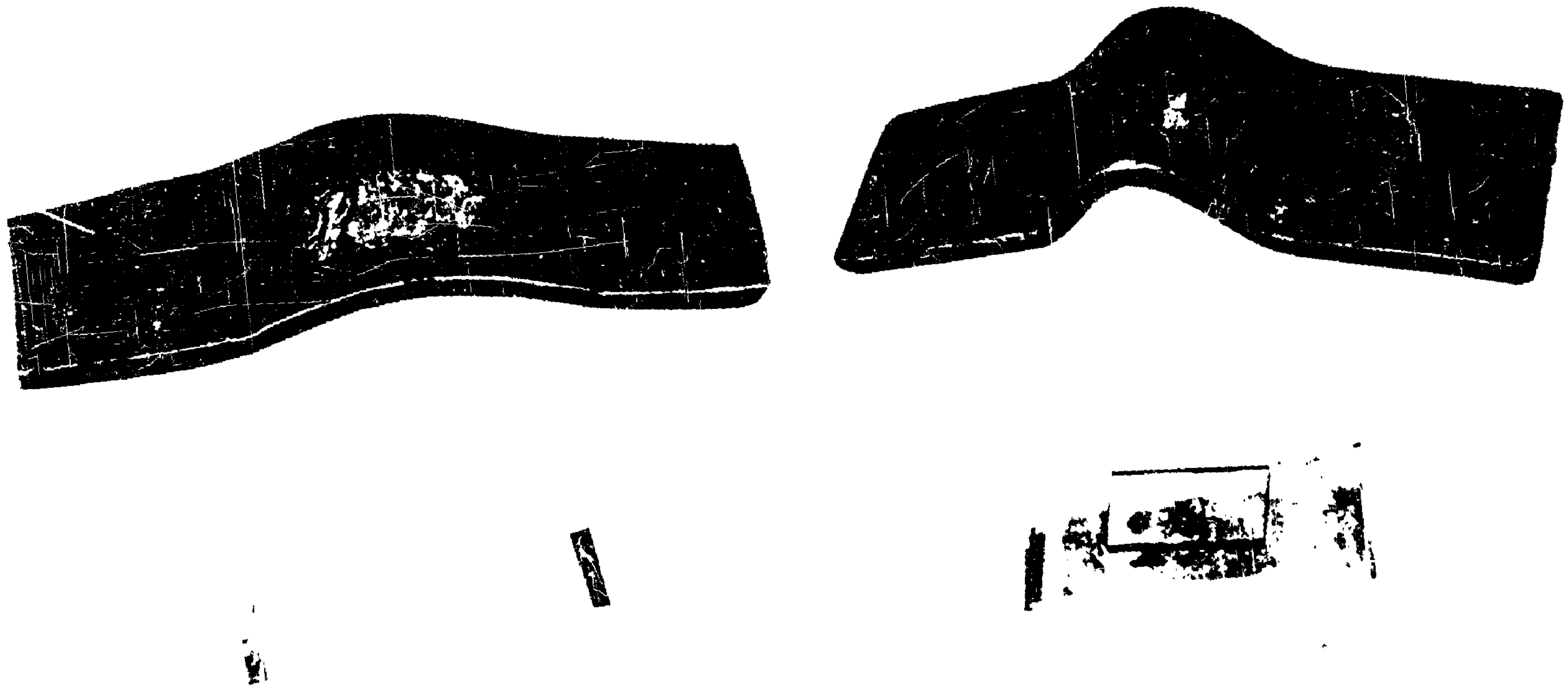

Figure 16. Different effects produced by long and short duration impulses. A quarter-inch thick lead plate was impacted by a 1"x2", 8 mil Mylar flyer, shown on the left, producing a loading time of approximately 0.2 microsecond causing spallation. On the right is shown a similar sample impacted with a 1/8 inch thick Lucite flyer causing primarily structural deformation by this two micro-second duration impulse. Both impacts were approximately at the same total impulse causing two different effects.

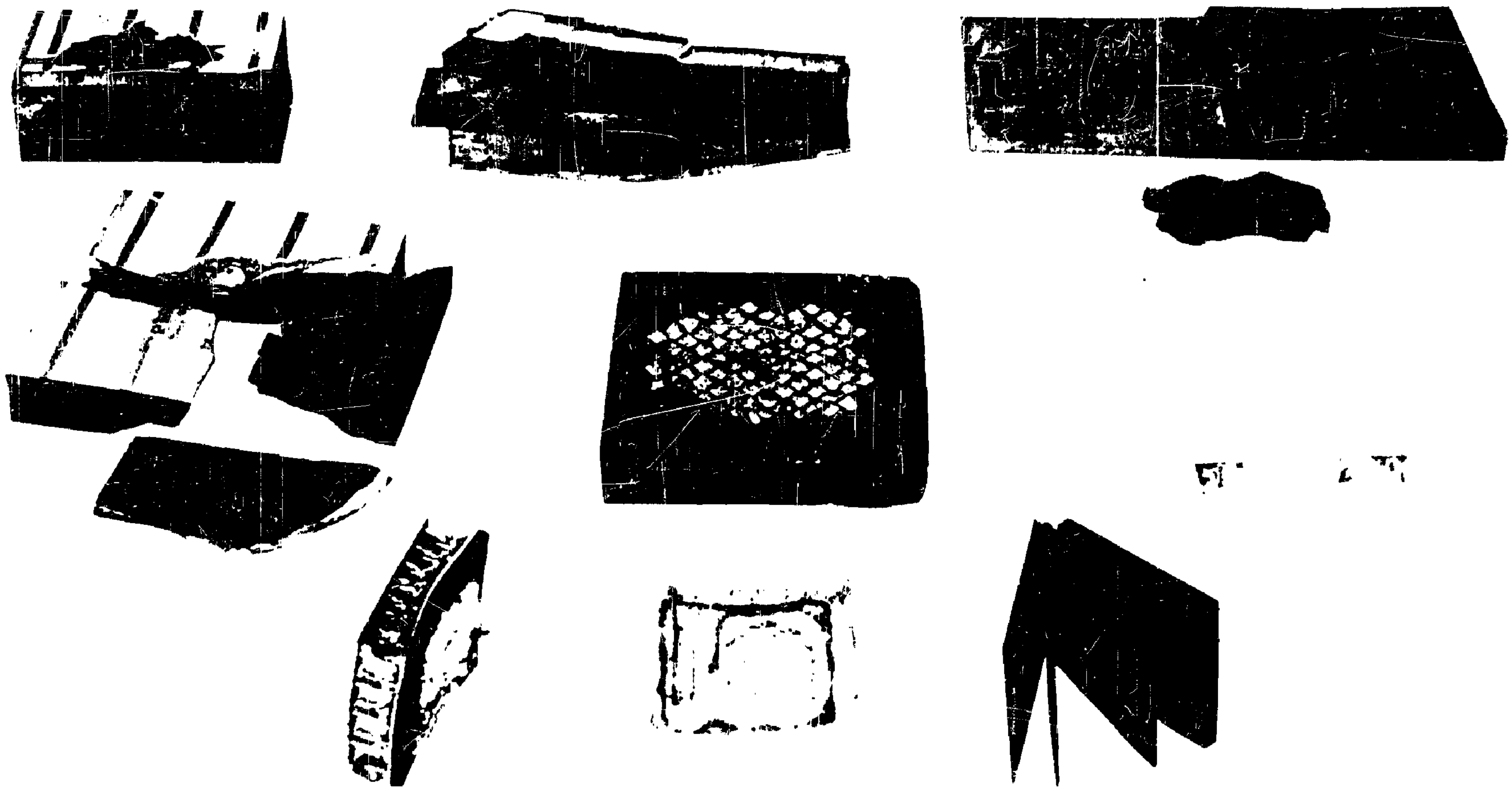

Figure 17. Various types of damage exhibited by different material configurations. From left to right and top to bottom we have internal cracking, back plate separation and spallation of back covering; structural deformation, delamination and separation along oblique layers; bond failure and internal spall of outer material; internal spallation, back plate failure and spallation of back covering; spallation of silica loaded hexcell, large area spallation of homogeneous plastic caused by long time impulsive loading; compression of hexcell shock absorbing material and removal of outer coating; front surface spall of an elastic coating; delamination of fiberglass.

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Rpt. No. AFSWC-TDR-61-75. ACCELERATION OF THIN PLATES BY EXPLODING FOIL TECHNIQUES. Jan 62, 37 p, incl illus., tables, 8 refs.
Unclassified Report

A technique for the acceleration of thin plates to high velocities by exploding foils has been developed. These plates, primarily Mylar and Lucite with areal dimensions up to 3 inches x 3 inches and thicknesses from a few mils to a quarter of an inch, are used to produce a high-impulse, short-time loading of materials for the purpose of material dynamics at high pressures. Velocities up to 5×10^5 cm/sec have been achieved. A brief description of equipment including the capacitor system, cameras,

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2. Capacitors
3. Dynamics
4. Impact testing
5. Peak pressure devices
6. Pressure
7. Shock hydrodynamics
8. Shock testing
9. Structural materials--effects of blast
10. Test equipment
11. Transducers
12. Velocity

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II. D.C. Wunsch, Lt, USAF; T.D. Soapes, Capt, USAF; A.H. Guenther, Dr.
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